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ADAPTIVE ROBOTIC NEURO-REHABILITATION HAPTIC DEVICE FOR MOTOR AND SENSORY DYSFUNCTION PATIENTS

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ABSTRACT

A study of Christopher[1]et.al., statedthat millions of people are affected bymotor and sensorydysfunctionacross the globe. An individual's standard of living is adversely affected with motor and sensory dysfunction. This research focuses on the current state-of the art robotic devices in vogue for neuro-rehabilitation of motor and sensory dysfunction patients. A combined qualitative and quantitative object-oriented case study is conducted with a population having mild to severe dysfunction. The inclusion criteria for sampling of study population are as follows: Patients with gross motor functional disability, developmental stage and chronic symptoms stage with a stable cardio-pulmonary state. Inexpensive miniature robotic devices like exoskeletons and end-effectors are considered in the present research as they facilitate tele-rehabilitation also. The double-folded aim of this study focuses on the following points: The extent to which the present robotic devices are sufficing the needs of patients with motor and sensory dysfunction and the scope of designing and developing a cost-effective neuro-rehabilitation haptic device to suffice the needs in a better way. The clotting of the blood in the brain is the root causal factor for motor and sensory dysfunction. If the drug is delivered on-time before the blood completely clots, severe damage to the motor and sensory nerves can be controlled and hence the dysfunction of body parts can be avoided. The current study also aims at developingneuro-rehabilitation haptic device which delivers drug on-time, and it is further studied in comparison with the current state-of-the art robotic devices. Robotic device aided neurotic study post brain-trauma contributed for deciphering the brain-plasticity and efficacy of these technologies.It is concluded that the presently developed neuro-rehabilitation haptic device is superior in terms of performance, comparatively. Comparative study showed promising results in the neuro-rehabilitation of patients with sensory and motor dysfunction.

KEYWORDS: Robotics, Neuro-rehabilitation, Haptics, Motor & Sensory Dysfunction

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Original Article

1. INTRODUCTION

In the current scenario, robotic devices are gaining their momentum in assisting the patients with motor and sensory dysfunction. This paper presents the various Neuro-rehabilitation motor and sensory assessments that are in practice as on date. The satisfactory levels of the patient, after utilizing the haptic devices are not considered by the current assessment practices. Hence, the current research brings the term 'Satisfactory Index (SI)' into picture, which represents the satisfaction of the patient in using the assistive neuro-rehabilitation devices. The rehabilitation techniques that are in use at present, like site-based drug delivery, occupational therapy, physio-therapy and massage therapy are limited in terms of applicability and performance. Hence, there is aneed for development of a novel neuro-rehabilitation haptic device for motor and sensory dysfunction

patients with on-time drug delivery system.

1.1. Neuro-rehabilitation Motor and Sensory Assessments

- The highly reliable Fugl Meyer Assessment (FMA)is developed by Gladstone et.al.,[2] and it isused to assess five major areas of human body viz., motor function, joint function, joint pains, sensoryfunction and balance.
- Taub et al.,[3] developed Wolf Motor Functional Test (WMFT), and it is used to assess strength, function alability and time of performance in the patients.
- Nicholas L et.al.,[4] stated the assessment method namely Boston Naming Test (BNT) for vocal dysfunction in these patients.
- Wechsler et.al.,[5]deigned Wechsler Adult Intelligence Scale (WAIS) with verbal and performance in relation to memory, picture management, vocabulary and assembly of objects.
- Barrecaet.al.,[6]uses the assessment method Chedoke Arm and Hand Activity Inventory (CAHAI) in which certain activities of daily life are needed to be completed during the test.
- Benton et al.,[7] presented Benton Visual Retention Test(BVRT), which analyses the visual perception and memory of the motor and sensory dysfunction patient.
- Rehabilitation Institute of Chicago and Mahoney et.al., introduced Black Box Test (BBT)[8] which evaluates manual dexterity of upper-limb motor function.
- Mahoney et.al.,[9] and Rehabilitation Institute of Chicago introducedJeben Hand Function Test (JHFT) which tests the hand, wrist and fingers functionality post stroke in the patients.

1.2. Neuro-rehabilitation Devices

Neuro-rehabilitation haptic devices range from Hand gloves to Exoskeletons. In order to recover the proper functioning of the bodily organs, the physiology has to be studied properly. As per literature, it is inferred that so far, the research concentrates only on physical therapeutic methods of recovery rather than the psychological therapeutic methods. The present research concentrates on the physio-psychological therapeutic methods, which is a blend of both physical and psychological therapeutic method. When a Robotic device is developed, the needs of the patient are to be addressed for physio-psychological recovery.

- Full Range of Motion (ROM) is possible by Robotic device of Loureiro et al.,[10] which has positive feedback which encourages motion and compliance. It is used for Neuro-rehabilitation of upper limb.
- In Robotic devices, Adamovich et al.,[11] stated that learning motor skills which is affected by new motor, skills and intensity are essential for speedy recovery.
- Ward et al.,[12] stresses the prominence of beginning the neuro-rehabilitation therapies as early as possible after the stroke, because it is observed that there is an increase in the motor area activation in the first couple of days rather than the following days.
- Linear and rotational friction in Exoskeletons is accounted by an algorithm developed by Frisoliet at.,[13-14]. They

compared the utility of kinesthetic feedback and cutaneous feedback.

- Brain Computer Interface(BCI) for navigation and bidirectional communication with Amyotrophic Lateral Sclerosis (ALS) patients is demonstrated by Escolano et al.,[15] In this case, the synchronization of controlled system with BCI is the problem that is faced. The current research focuses on this problem, and an algorithm is developed to address this issue.
- While grouping the population in the presentstudy, the concept of Lum et al.[16]is considered. According to this study, the population is classified into three types viz., bimanual, unilateral and combination mode. It is observed that combined mode exhibited greater improvement compared to the individual mode. This is validated in the present study also.
- A 3-Degrees of Freedom(DOF) Hand Wrist Assisting Robotic Device (HWARD) has a wide Range of Motion(ROM) and it is used for extension of fingers, thumb and wrist.

In the above literature, it is to be noted that the assessment methods are concentrated only on physical organs, but the stress levels and satisfaction of the patient are not taken into account. Moreover, the emphasis is also to be laid on the timely drug-delivery to the motor and sensory dysfunction patients, as the time-lag in the drug delivery causes severe damage to the patient. It may be as severe as resulting even in permanent disability. Hence, keeping the above concepts in view, there is a need to develop a better version of Neuro-rehabilitation Haptic device that addresses these issues.

2. NEURO-REHABILITATION HAPTIC DEVICE

The Neuro-rehabilitation haptic device is developed and then tested with Electromyography (EMG) placed on both the healthy and affected limbs. The device that is developed here is so flexible that when placed in an orthotic shell, it can be used interchangeably well with both the right and leftlimbs. Hence, the rehabilitation of both the limbsis possible. In this device, force feedback is delivered to the finger or thumb in order to ensure closed loop control of the device. This section presents the detailed description of the working principle of Neuro-rehabilitation of haptic device.

Gross motor skills of the population arestudied to comprehend the Satisfactory Index (SI) of the patients. In this explorative phase, this research concentrates on the neuro-psychological and neuro-physical attributes by testing a population sample of 52 motor and sensory dysfunction patients. This provided meaningful insights to the performance of the currently developed Neuro-rehabilitation haptic device in terms of Satisfactory Index (SI). When the Neuro-rehabilitation Haptic Device feedback is in corporated into the virtual reality environment, it is observed that the sample population exhibited better Satisfactory Index (SI), compared to when it is without virtual reality.

2.1.Operational Algorithm of Neuro-Rehabilitation Haptic Device

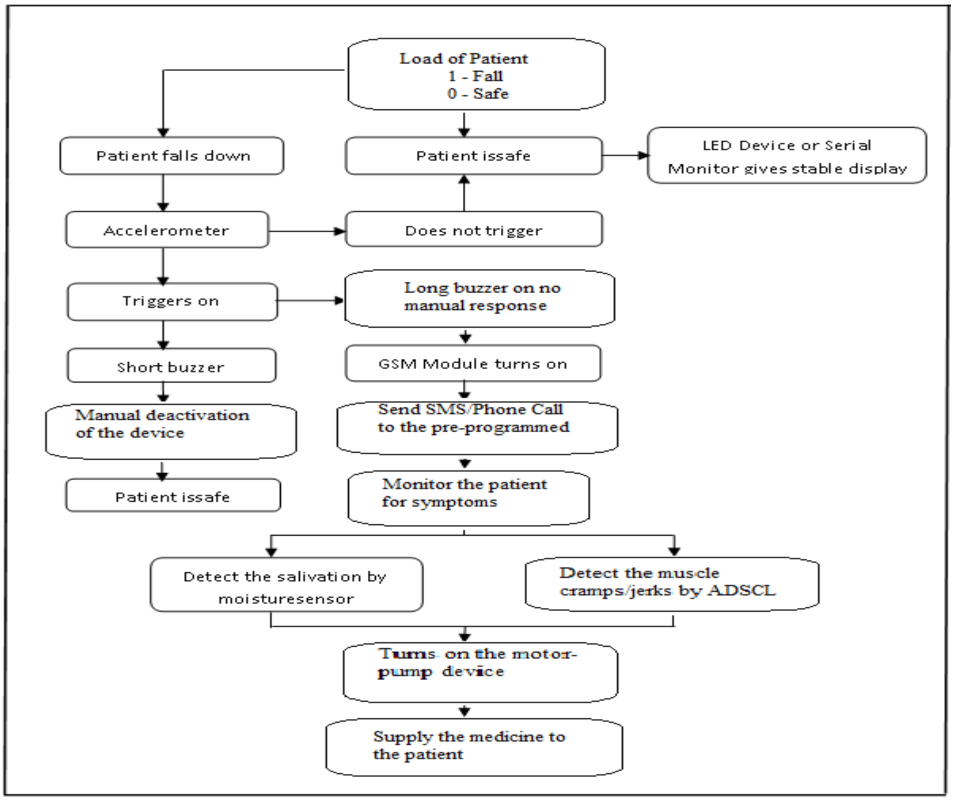

Figure 1: Algorithm of Neuro-Rehabilitation Haptic Device.

2.2.Operational Sequence of Neuro-rehabilitation of Haptic Device

The digital load detector isfixedto the patient. Digital load detector reads '1' when the patient falls and '0' if the patient issafe. If the patient falls down due to motor and sensory dysfunction, accelerometer triggers 'on'. If the accelerometer does not trigger on, it indicates that the patient is safe and the Light Emitting Diode Display or the Serial monitor gives a stable display. Two types of provisions are provided on the accelerometer for buzzing. Short buzzer indicates that the stroke is mild and the patient becomes alert and deactivates the accelerometer. Long buzzer indicates that the stroke is severe and there is no manual response of the patient due to motor and sensory dysfunction. Long buzzer triggers the Global System for Mobile Module 'on' which, further sends Short Message Service alert or phone call to the pre-programmed contacts. At this stage, high-end patient rescue module turns on and monitors the patient for symptoms. Salivation of the patient is detected by moisture sensor and the muscle cramps are detected. With this, motor-pump device is turned on and the medicine is supplied to the patient.

3. RESULTS

Table 1: Tabulated Form of Population Study and Results

Patient Code	Gender	Age	Hemisphere Affected	Motor/Cognitive Deficiency	End-Effectors (SI)	Exo-Skeletons (SI)	Neuro-Rehabilitation Haptic Device(SI)
AF	Female	40	Right	Hand	0.78	0.82	0.91
BF	Female	42	Right	Wrist	0.78	0.71	0.82
CF	Female	44	Right	Upper Limb	0.68	0.72	0.71

Table 1: Contd.,

DF	Female	45	Right	Lower Limb	0.74	0.88	0.85
EF	Female	47	Right	Fingers	0.82	0.86	0.84
FF	Female	49	Right	Cheek	0.88	0.81	0.89
GF	Female	51	Right	Vision	0.81	0.84	0.87
HF	Female	52	Right	Lower Arm	0.78	0.82	0.83
IF	Female	55	Right	Upper Arm	0.84	0.86	0.91
JF	Female	57	Right	Feet	0.78	0.81	0.92
KF	Female	59	Right	Toes	0.77	0.83	0.89
LF	Female	61	Right	Neck	0.73	0.76	0.81
MF	Female	63	Right	Head	0.84	0.85	0.89
NF	Female	45	Left	Hand	0.81	0.78	0.92
OF	Female	43	Left	Wrist	0.72	0.73	0.78
PF	Female	42	Left	Upper Limb	0.83	0.86	0.81
QF	Female	47	Left	Lower Limb	0.91	0.88	0.94
RF	Female	49	Left	Fingers	0.93	0.91	0.89
SF	Female	55	Left	Cheek	0.88	0.85	0.87
TF	Female	66	Left	Vision	0.84	0.87	0.88
UF	Female	62	Left	Lower Arm	0.83	0.92	0.91
VF	Female	56	Left	Upper Arm	0.78	0.86	0.84
WF	Female	53	Left	Feet	0.79	0.83	0.85
XF	Female	58	Left	Toes	0.72	0.78	0.79
YF	Female	54	Left	Neck	0.88	0.87	0.90
ZF	Female	47	Left	Head	0.81	0.90	0.89
AM	Male	49	Right	Hand	0.79	0.76	0.86
BM	Male	42	Right	Wrist	0.74	0.78	0.85
CM	Male	44	Right	Upper Limb	0.76	0.70	0.78
DM	Male	46	Right	Lower Limb	0.80	0.74	0.83
EM	Male	52	Right	Fingers	0.87	0.82	0.84
FM	Male	55	Right	Cheek	0.77	0.81	0.84
GM	Male	59	Right	Vision	0.89	0.90	0.88
HM	Male	61	Right	Lower Arm	0.90	0.88	0.89
IM	Male	63	Right	Upper Arm	0.84	0.88	0.90
JM	Male	65	Right	Feet	0.87	0.89	0.86
KM	Male	47	Right	Toes	0.83	0.89	0.90
LM	Male	55	Right	Neck	0.92	0.89	0.90
MM	Male	41	Right	Head	0.89	0.85	0.82
NM	Male	44	Left	Hand	0.84	0.82	0.83
OM	Male	48	Left	Wrist	0.82	0.86	0.87
PM	Male	43	Left	Upper Limb	0.78	0.82	0.84
QM	Male	54	Left	Lower Limb	0.79	0.84	0.86
RM	Male	64	Left	Fingers	0.83	0.86	0.84
SM	Male	62	Left	Cheek	0.84	0.89	0.91
TM	Male	59	Left	Vision	0.76	0.79	0.78
UM	Male	47	Left	Lower Arm	0.79	0.82	0.86
VM	Male	42	Left	Upper Arm	0.84	0.78	0.88
WM	Male	58	Left	Feet	0.85	0.79	0.83
XM	Male	46	Left	Toes	0.90	0.87	0.88
YM	Male	54	Left	Neck	0.83	0.87	0.85
ZM	Male	64	Left	Head	0.78	0.81	0.84

4. DISCUSSIONS

The present research includes the concept of ‘Satisfactory Index’(SI), which takes into account the satisfaction of the motor and sensory dysfunction patients upon using the neuro-rehabilitation haptic device. A comparative study has been made

between the End-effectors, Exo-skeletons and currently developed haptic device. The quantitative and qualitative motor and sensory functions are taken as the criteria for evaluation. The detailed review of the therapeutic survey showed that the results have improved by the use of this Haptic device. It is vivid that the Virtual Reality based Haptic device developed is comparable to End-effectors and Exoskeletonsthat are in vogue in the present day.

Motor function of the patient improved by using the Virtual Reality based Robotic Haptic device like a Robotic glove. Theresults are in corroboration with the factstated by Lum P et al.,[18], Krebs H et al.,[19],Mehrholz J et al.,[20]that Robotic devices are more efficient than Conventional therapies, in terms of improvement in efficiency of motor and sensory dysfunction patients.

5. CONCLUSIONS

- The study results clearly conclude that the developed Neuro-rehabilitation device contributes to the domains of improving motors kills and sensory skills by on-time drug-delivery, before severe damage occurs to the motor and sensory dysfunction patient by sensing symptoms, a priori by virtual reality.
- The comparative study on sample population indicated that the currently developed Neuro-rehabilitation Haptic device exhibited better efficiency compared to End-effectors and Exo-Skeletons, in terms of Satisfactory Index(SI).
- The study concludes that End-effectors and Exo-Skeletonsh as got it sown limitations, which can be overcome by this Neuro-rehabilitation Haptic Device. The Virtual Reality incorporated Neuro-rehabilitation Haptic Device performs better, even though the initial cost is slightly higher over the device without virtual reality version. The slightly higher cost is accountable when the performance, efficiency and satisfactory index are taken into consideration as the neuro rehabilitation goals are achieved better with virtual reality version.

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REFERENCES

1. *Christopher and Dana Reeve Foundation. Available from: http://www.christopherreeve.org/. Accessed January2019.*
2. *Gladstone D, Danells C, Black S. The Fugl-Meyer assessment of motor recovery after stroke: a critical review of its measurement properties. Neurorehab Neural Repair. 2002; 16(3) :232–40.*
3. *Chourasia, R. C., & Bhardwaj, A. K. (2014). Design Estimation of Brushless SEDC Motor for Speed Control by using VariousControllers. IJEEER ISSN (P).*
4. *Taub E, Morris D, Crago J. Wolf motor function test(WMFT) manual. Available from:*

   https://www.uab.edu/citherapy/images/pdf_files/CIT_ Training_WMFT_Manual.
5. *Nicholas L, Brookshire R, MacLennan D, Schumacher J, Porrazzo S. The Boston Naming Test: Revised administration and scoring procedures and normative information for non-brain-damaged adults - Clinical Aphasiology Conference 1988.*
6. *Sures, H. Fortification and culpability analysis of three phase induction motor using labview.*

7. *Wechsler D, Wechsler adult intelligence scale-revised. Available from: http://www.cps.nove.edu/cpphelp/WAIS-R.html. Accessed April 2019.*

8. *Barreca S, Stratford P, Masters L, Gowland C, Lambet C, Griffiths J, McBay C, Dunkerly M, Miller P, Huibregts M, Torresion W. The Chedoki arm and hand activity inventory. Available from: http://www.cahai.ca/layout/content/CAHAI-Manual-English-v2.pdf. Accesses August 2018.*

9. *Benton A. Benton Visual Retention Test, 5^{th} ed. Available from: http://cirrie.buffalo.edu/database/20770/ Accesses May 2019.*

10. *Padghan¹, K. K., Modak, A. P. J., & Narkhedkar, A. Design and analysis of cad based human powered flywheel motor by using quick return ratio one mechanism.*

11. *Rehabilitation Institute of Chicago, Rehabilitation measures database. Available from: https://www.rehadmeasures.org/default.aspx. Accesses March 2019.*

12. *Mahoney F, Barthel D. Functional Evaluation: The Barthel Index. Maryland State Med J. 1965; 14:56–61.*

13. *Loureiro R, Harwin W, Nagai K, Jhonson M. Advances in upper limb stroke rehabilitation: a technology push. Med Biological EngComput. 2011; 49 (10): 1103–18.*

14. *Adamovich S V, Fluet G, Tunik E, Merians A S. Sensorimotor training in virtual reality: a review. Neurorehabilitation 2009; 25(1): 29–44.*

15. *Ward S, Brown M, Thompson J, Frackowiak S, Neutral correlates of motor recovery after stroke: a longitudinal fMRI study. Brain 2002; 126(11): 2476–96.*

16. *Frisoli A, Bergamasco M, Wu S, Ruffaldi E. Evaluation of multipoint contact interfaces in haptic perception of shapes. Multipoint interaction with real and virtual objects. Berlin: Springer-Verlag. 2005; 18:177–88.*

17. *Frisoli A, Solazzi M, Reiner M, Bergamasco M. The contribution of cutaneous and kinesthetic sensory modalities in haptic perception of orientation. Brain Res Bull. 2011; 85(5): 260–6.*

18. *Escolano C, Murguialday A, Matuz T, Birbaumer N, Minguez J. A telepresence robotic system operated with a p300 based brain computer interface: initial teastes with ALS patients. IEEE Annual International Conference on Engineering in Medicine and Biology Society (EMBC'10). Buenos Aires, Argentina, September 2010.*

19. *Lum P, BurgarC,Der Loos M V, Shor P, Majumdar M, Yap R. The mime robotic system for upper limb neurorehabilitation: results from a clinical trial in subacute stroke. 9^{th} IEEE International Conference on Rehabilitation Robotics. Chicago, IL, June 2005.*

20. *Takahashi C, Der-Yeghiaian L, Le V, Cramer S. A robotic device for hand motor therapy after stroke. IEEE 9^{th} International Conference on Rehabilitation Robotics (ICORR'05). Chicago, IL, June 2005.*

21. *Lum P, Burgar C, Shor P, Majumdar M, der Loos M V, Robot assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke. Arch Phys Med Rehabil. 2002; 83(7):953–9.*

22. *Kayode, G. M., Borode, M., & Adedokun, M. O. Community driven development project: a study on the impact of motorized borehole water project in irasa, ado-ekiti, nigeria.*

23. *Krebs H, Hogan N, Aisen L, Volpe T. Robot-Aided neurorehabilitation. IEEE Trans Rehabil Eng. 1998; 6(1):75–87.*

24. *Mehrholz J, Hadrich A, Platz T, Kugler J, Pohl M. Electromechanical and robotic-assisted arm training for improving generic activities of daily living, arm function and arm muscle strength after stroke. Cochrane Database Syst Rev. 2012 Jun 13;(6): CD006876.*

Appendix-1

Abbreviations

S.No.	Abbreviation	Full Version
1	FMA	Fugl Meyer Assessment
2	WMFT	Wolf MotorFunctional Test
3	BNT	Boston Naming Test
4	WAIS	Wechsler Adult Intelligence Scale
5	CAHAI	Chedoke Arm and Hand ActivityInventory
6	BVRT	Boston Visual Retention Test
7	BBT	Black Box Test
8	JHFT	Jebsen Hand Function Test
9	ROM	Range of Motion
10	SI	Satisfactory Index
11	BCI	Brain Computer Interface
12	ALS	AmyotrophicLateralSclerosis
13	HWARD	Hand WristAssistingRoboticDevice
14	EMG	Electromyography

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